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UNIVERSITY OF PENNSYLVANIA
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References to the use of high frequency sources in geophysics.

Geophysics XXII (1957) pp 345-7.

U.S. Geological Survey, Washington D.C. Work done by I. Zietz and L.C. Pakiser. Transducer (300 lbs weight, 25" diam., 18" high, $2\frac{1}{2}$ kwatt output) used to couple energy to the ground. Frequencies of 6, 11.5 and 16 Kc/s used. To match transducer to the ground shallow pits filled with water or grease used. The transducer had been designed for use in water. Reflections from as deep as 250 ft thought to have been observed.

Geophysics V (1940) pp 1-14.

Original work done by Humble Oil Co. Vibrator system of magnet on an aluminium tube used (weight 300 lbs, tube 12ft long) smaller apparatus used in further tests (tube 8ft long, 3" diam). Frequencies used up to $1\frac{1}{2}$ Kc/s.

Geophysics XXV No 1 (1960) pp 95-105.

Continuous wave seismograph. Frequency range not stated, but presumably only up to circa 300 c/s.

Geophysical prospecting V No 4 (1957) pp 381-91.

General article by F.F. Evison on various seismic sources. Mention is made of several transducer sources used by Evison, frequencies up to 800c/s used. The work was mainly done as part of a scheme for the investigation of wave propagation rather than for survey purposes.

AN EXPERIMENTAL SONIC INSTRUMENT
FOR ARCHEOLOGICAL EXPLORATION.

Return to
Ralph
Many thanks -
For use in education
JHR

Title? →

~~Problems in the Development of a~~
SONIC Instrument

By Elizabeth K. Ralph
and

Grey MacLaughlin

Applied Science Center for Archaeology, University Museum, University of Pennsylvania, Philadelphia, Pa.

Seismic instruments have been in use for geophysical prospecting for several decades. ^{however,} Since they are designed primarily for the location of geologic ^{al features} structures ^{located in} favorable for deep deposits of economic value, ^{possible} it is not surprising that they are not readily adaptable for use in exploring and outlining, from the surface of the earth, archaeological ruins and artifacts buried ^{at shallow depths,} under shallow alluvium. The ease with which the low frequency waves, produced and detected by seismic instruments, penetrate to the deep layers without "noticing" the archaeological or historical ^{remains} ruins along the way has been illustrated ^{in the report} by the ~~results~~ of the survey made at Harpers Ferry by H. Carson. * Our efforts, therefore, have been directed toward the development of an instrument capable of detecting objects to depths of 30 ft. and determining an accurate estimation of depth and possibly of size. ¹

* See page — in this issue.

1. We are indebted to the National Science Foundation for the financial support which, ^{enabled} under the direction of Dr. Froelich Rainey, (Director of the University Museum and of The Applied Science Center for Archaeology) ^{to launch} enabled this program of instrument ^{al} development, ~~to be started.~~ Other contributors are mentioned later in the text.

is c the accepted
symbol for sound
wave velocity?

I thought it was the
velocity of light,
maybe consider
using v

Might help if
give a typed ~~of~~
 v and value of
wave length of
20,000.000 cm

I see it's
given later!

Basically, the problem with existing seismic equipment, is that the seismic waves are too long. The long waves pass by small objects with no measurable results. High frequency sound ^{waves} up to 20,000 cycles per second and ultrasonic, above 20,000 ~~cycles~~ ^{CPS (because of their shorter wavelengths)} ² have the desirable feature of being directional, ^{and can} produce ~~or~~ "shadows" ^{or} and reflections from relatively small objects or anomalies.

on
and ground

Basically, the wavelengths of seismic type waves are too long. Ultrasonic waves, (frequencies above 20,000 Cps) exhibit rectilinear propagation because of their short wave lengths.² The wave motion is, therefore, transmitted in a straight line, and the energy cannot travel around sharp discontinuities. It is this property which makes it possible to use these waves ~~XXX~~ for the location of small objects, since any small inhomogeneity will cast a sharp shadow behind it.

When we go to ^{these} higher frequencies, however, we encounter another problem -- that of attenuation. The earth is a very poor transmission medium for ultrasonic waves; and the higher the frequency, the greater are the losses in intensity.³

2. $\lambda = \frac{c}{f}$ where λ = wavelength
 f = frequency of vibration
 c = velocity of propagation
 c is dependent upon the elastic constants and density of the medium in which the wave is propagated.

3. $I = I_0 \frac{e^{-gr}}{r}$ (for ultrasonic frequencies)

where I = amplitude at distance r from the source

I_0 = initial amplitude

g = attenuation constant which is dependent upon the material, but g is roughly proportional to the square of the frequency. *in some media, g is given by $m - a \lambda^{-2}$*

~~Formula - assumes homogeneous medium~~

Therefore, for practical purposes we have to compromise and conduct our experiments in the sonic range (500-20,000 cps). It happens also that this range is appropriate for the size of the objects sought. For example, in a medium such as shale with a velocity ~~at~~ of 2000 ft/sec, a frequency of 5000 cps would have a wavelength of $2/5$ ft., or approximately 5 inches. Since reflections occur when the dimensions of an anomaly are as large or larger than a wavelength, objects of 5 inches or larger can be detected with fairly low frequencies.

Even at these comparatively lower frequencies, however, severe losses are encountered.

No # Only a small portion of the energy starting out from a given source will reach a given distant point. It will continuously diminish in intensity along any path which it may follow. The decrease in intensity is due to two quite different effects. One is the divergence of the sound rays as they radiate from the source, which distributes the energy over a surface of ever increasing area. The other is the absorption of energy by the medium and the scattering of the energy by reflectors contained in the medium. The first of these introduces what is known as the spreading loss and the second, the attenuation loss. The two together constitute the propagation loss which is characteristic of the medium at a given location. There are important differences between the two losses. The spreading loss, associated with a given path length depends upon the distance to the source, but it is independent of frequency of the acoustic wave being transmitted. The attenuation loss, on the other hand, is a function of the frequency of the wave. The resultant effect of these two losses, considered in conjunction with the magnitude of the transmitted signal and the stray noise, both internal and external, of the receiving

✓ range of the
equipment

you haven't
talked about the receiver yet
you mean only the transmitter?
maybe you should say so

system, determines the range of the equipment. As the loss due to the spreading is independent of frequency, the attenuation loss will determine the maximum frequency usable for any given range (assuming constant power output from the ~~acoustic~~ source).

To help with this problem, we may, therefore, change from the detection of continuous waves to that ^{of} repeated impulses. This will enable us to use more sensitive detection techniques, make improvements in signal to noise ratios, facilitate the interpretation of results, ~~and so forth~~. ^{AND EMPLOY MUCH HIGHER TRANSMITTER POWER.} The term "impulse" is somewhat ambiguous because most seismic instruments employ single or multiple "shot" impulses which then impart waves of ^(mixed ? joint) low frequency into the earth. In this case, we are using impulses with constant repetition rates of 10 to 5 cps, ^{> per} each one of which imparts a sound ^{burst} of higher frequency into the ground. ^{need}

~~"R" waves or Raleigh waves, involving a vertical motion of the particles at right angles to the direction of wave advance.~~

~~"Q" waves, a horizontal motion of the particles at right angles to the direction of wave advance.~~

~~Two additional types were detected for the first time and identified from records obtained during the A bomb test in New Mexico, July 16, 1945. They are "H" and "C" types. The "H" wave involves a circular motion of the particles at right angles to the wave advance. The "C" or coupled wave also involves a circular motion but it is tilted from right angles to the wave advance.~~

~~The two modes of wave propagation of interest in the seismic probe are the P and S body waves, with the P wave at present seeming the most suitable. A preliminary investigation of literature indicated very little information to date on the use of high frequency sound for the detection and location of anomalies in the earth. This fact is very surprising, as the applications, including military uses, seem very numerous. A few experimenters have used sound of a few~~

thousand cycles with excellent penetration, usually for signaling.

The loss of energy in earth is due to several complex effects and it would be useless to try to extract more than approximations from the theories. Most of the data from SONAR and NDT (non-destructive testing) has been obtained experimentally but certain conclusions can be drawn.

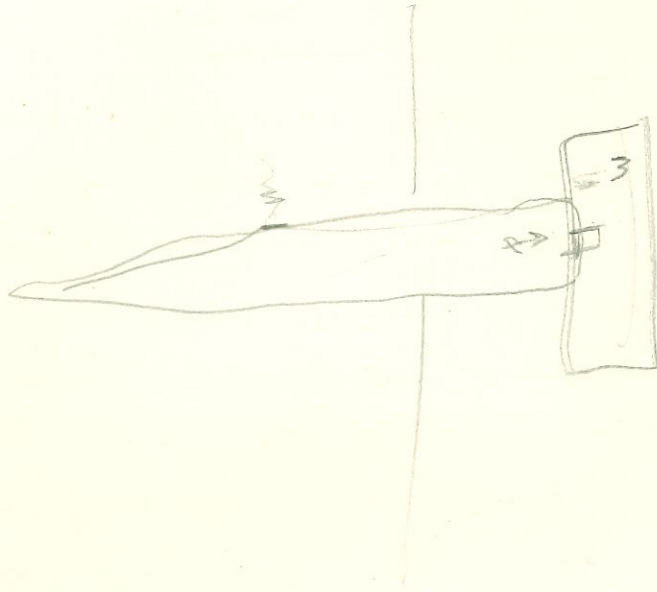
Omit

Theoretically, the attenuation varies approximately as the square root of the frequency until the wavelength approaches the size of particles imbedded in the transmitting medium. At this point, the attenuation will increase as the square (approximately) of the frequency. An analogous effect is the interference with visibility when fog particles are present, as the scattering by the large fog particles reduces visibility. However, for the ranges of interest, a considerable choice is available as regards frequency. The short ranges required for archaeological prospecting should permit wide choice in the selection of frequency with reasonable power output from the energy source. The frequency ?

Progress in the design of an instrument based on these principles has been hampered by the fact that very few measurements have been made of the transmission characteristics of sonic waves or impulses in the earth. We have been in the dark, ^{therefore,} about initial power requirements, ^{the} variation of attenuation with frequency, the effect of soil composition, and the ^{MAJOR} ~~big~~ problem of coupling the sound source to the ground without excessive losses. To couple the transmitter (or transducer) to earth, a very small motion with great pressure is necessary. Forces of the order of several hundred pounds per square inch are required to couple ^{sufficient} ~~considerable~~ energy into the

earth. An impact source will operate efficiently at low ~~XXXXXX~~-
~~XXXXX~~ frequencies but it is deficient in high frequency energy content.
However, a small high velocity ~~type~~ ⁺ impact source shows some promise.

~~Also, some materials designed for operation in cleaning devices may
be modified for use in transducers.~~



equipment which sends ... and observes ...
yes
Smith

Preliminary studies (by MacLaughlin) and previous experience with SONAR and RADAR equipment indicated that a reflection ~~type~~ ^{that is, the} system sending a pulse of (P-type longitudinal) sound waves into the ground and observing the echo or reflection electronically, would provide the greatest amount of information. An echo ranging system was, therefore, assembled from modified RADAR equipment and improvised pickups. An impact source was used as the transmitter. With this bulky equipment, excellent reflections were obtained from a rock layer about twelve feet deep and indications were obtained of rocks at intermediate depths (See Fig. 1).

not clear

The preliminary tests and subsequent experiments with geophone (the receiver) materials were encouraging. Therefore, a portable unit was designed and built (the MacLaughlin prototype). The circuits are transistorized and the detecting element is a 3-inch oscilloscope screen. The entire unit, complete with Nickel-Cadmium batteries, transducer and pickups, weighs just under 25 lbs. It employs a self-synchronized system— a trigger pulse is obtained from the transmitter and the circuits are controlled by the externally generated impulse. This system is flexible and permits the unit to be used with any type of transmitter. The first transmitter designed for use with the portable unit consists of an electromagnetic hammer type with diaphragm resonating at approximately 5000 cps, and repetition rate of 10 cps. This and the geophone (placed beside it) are then coupled to the ground by means of tapered spikes (one for each) made of aluminum or plastic. The coupling is by the shear mode and provides the best coupling to firm ground yet obtained without ground preparation. However, the output of the transducer is greatest at low frequencies and falls off sharply at high frequencies. The performance at different frequencies was determined with selected geophones and tuned amplifiers. The geophones tested so far were made with piezoelectric materials - rochelle salt and barium titanate bender elements, both of which have adequate response characteristics up to 20 kc. Other types, magnetostrictive geophones, and improvements in these or piezoelectric

not clear

what
per second

^{should} types ~~may~~ furnish much greater sensitivity and noise discrimination.

The operation of the MacLaughlin prototype may be understood by following the block diagram (Fig. 2) step by step.

The impact of the hammer (1) produces a sync pulse from the synchronizing crystal (2), the pulse is amplified by sync amp. (3), triggers the blocking oscillator (4), the output pulse is fed to the flip flop (5) which turns ON. The ON condition of (5) activates a bootstrap linear sweep generator (6). The sweeplength control determines the sweep amplitude that turns OFF the flip flop (5). The linear sweep waveform is amplified to approximately 600 V by sweep amplifier (7), and then fed to vertical deflection plates of the C. R. T. ~~trace~~ during the sweep.

The sound pulse (11) coupled into the ground is reflected by any anomaly of sufficient size and is picked up by the geophone (12). The signal is amplified by signal amp (13) and coupled through the isolation transformer (14) to the horizontal plates of the C. R. T. (8). The signal appears on the sweep at a point dependent upon the travel time. To estimate the depth of a reflecting object, range marks are generated by (15). This circuit is a blocking oscillator that generates pulses at controlled intervals. The output pulses are mixed with the signals and appear as indices along the sweep. The range marks are adjusted to be at 0.5 meter intervals with average velocity of 2000 ft/sec. If work is being done entirely in one area, they may be adjusted to compensate for variation in velocity and indicate depth directly.

A very effective method of increasing the sensitivity of the receiver was used. This consists of the use of ^{a "long-persistence"} ~~special~~ cathode ray tube screen. The screen is a cascade screen with a double layer. The electrons bombard the inner "electron layer" to excite it to a high level of radiance and the energy of this layer is absorbed by the "outer glass layer" which emits light in the form of a time delayed phosphorescence. The inner or "electron" layer is usually zinc sulfide activated with silver and ^{fluoresces} blue at about 4510 angstroms. This wavelength efficiently excites the outer or "glass" layer which phosphoresces in the yellow portion of the spectrum at a wavelength of about 5630 angstroms. The blue flash can be removed leaving only the yellow

phosphorescence by the use of a filter equivalent to Wratten filter No. 15. The advantage of using this type of screen is to permit the build-up of the signal by repetitive sweeps as the signals occur at the same point on the sweep while the noise signals, being random in nature do not add, and are not visible. The effectiveness of this method is great, permitting reflections that are only small percentages of the background noise to be seen easily. In fact, during recent field tests, trouble occurred in the sync circuits causing irregularities in the sweep timing and reflections were not possible to obtain. This ^{special} ~~type~~ screen is commercially available and is designated Type P7. [When obtaining this type screen, the manufacturer should be told that the property of interest is the buildup of signals with repetitive sweeps. This is usually associated with low cadmium content of the zinc sulfide-cadmium sulfide phosphor (copper activated) used as the "glass layer". Considerable variation in different manufacturers' tubes exists due to variations in manufacturing methods and the buildup is not usually the property of interest in other applications. However, the voltage applied also varies the effect to some extent. With the C.R.T. used, 2500 to 2700 volt accelerating potential gave optimum results with a repetition rate of 8 to 10 sweeps per second. This type screen is not efficient when used with low accelerating potentials.]

Several photographs show ^{the} echo signals are attached and illustrate the operation of the experimental unit. To facilitate comparison of signals, the scale used in all photographs is the same, 20 milliseconds, corresponding to approximately twenty foot depths.

omit

One set of photographs (Fig. 3), is of particular interest as it illustrates the difference in detail obtained with very ^{low} frequencies to that obtained from higher frequencies. One illustrates echos below 400 cycles and the other, ~~illustrates~~ illustrates the increased definition using frequencies of up to 10,000 cycles. The echo detail of the high frequency signal apparently indicates the structure of the ^{TRAPPE} ~~trappe~~ rock layer.

The equipment is illustrated in Figs. 4 and Fig. 5.

Tests made with this experimental sonic probe indicated that ^{more} considerable field work is desirable before proceeding with the building of a second model. Information is needed concerning maximum and minimum velocity of sonic waves at different locations to establish ranges (travel time) and the design of the indicator range circuits. Also the attenuation at various frequencies will determine the sensitivity of the equipment and also the power required from the transmitter. Coupling the transmitter (transducer) and the receiver (geophone) to the ground becomes increasingly important as the range and frequency of operation increases.

Concurrently, ^{a foundation, members of the} Fortunately, because of the generosity of ~~Johnson?~~ of the Sun Oil ^{Co.}, and the fine cooperation of W. Harry Mayne, Vice President, and other members of the Petty Laboratories, Inc., experiments are being conducted on our behalf by the latter company in San Antonio, Texas.

As a start, propagation measurements were ^{conducted} conducted by Andrew O. Bergquist, Project Engineer, at frequencies in the range of 200 to 1600 cps with a low power continuous wave driver coupled to the earth through an oil medium (6 gallons in a plastic-lined hole one foot deep). A vertical spread of seven acceleration type detectors,

planted from 3 feet to a depth of 15 feet was used in conjunction with the symmetrically-located driver. The earth at this site (18 miles from San Antonio) consists of a sandy-clay soil having seismic velocity of about 1900 ft/sec to a depth of 30 ft. This investigation indicates, thus far, that ^{is not too} for continuous waves, attenuation ~~becomes~~ severe, ^{until the frequency exceeds 600 to 800 cycles,} ~~above 600 cycles,~~ ^{but} and that driver powers of some hundreds of watts probably will be required for fully reliable measurements to 25 or 30 feet, ~~(on a continuous wave basis).~~ ↗

~~It is anticipated that experiments currently in process at Petty with impulse sources will be more encouraging.~~

Experiments ~~currently~~ in process at Petty with impulse sources will furnish basic data on the transmission characteristics of pulsed waves, and, it is hoped, will provide the information needed for the assembly of a workable set of equipment.

In the meantime, fundamental studies of seismic and sonic wave behavior in the weathered layer near the surface of the earth, are ^{to} ~~are~~ ^{check exact name} being conducted by the Geophysical Service Division of Texas Instruments (Dallas, Texas) under the direction of Dr. Frederick Romberg. We are indebted also to Dr. Eugene McDermott, Chairman of the Executive Committee for this cooperative arrangement.

For use in this study, a ^{PORTABLE} multi-channel high frequency oscillograph with associated high frequency geophone pickups is being designed and built by MacLaughlin Electronics. This instrument is designed to record reflections from a single impulse produced by a small explosive charge or a bullet fired into the ground.

The unit will record ^{VIBRATIONS} ~~sound~~ up to 2000 cycles. The recordings are made ^{on} a 10-second Polaroid film and are immediately available for observation. The ~~use of~~ ^{ANALYTICAL} instrument will permit the use of ~~all~~ ^{both} methods ^{the} of ~~analysis~~ that have been developed for prospecting and detection and identification of ~~nuclear~~ explosions at a distance.

In the meantime, fundamental studies of seismic (or sonic) wave behavior near the surface of the earth ^{IN THE WEATHERED LAYER,} are being conducted ¹ on our behalf (?) by the Texas Instruments Co. Inc., (Dallas, Texas) under the direction of ~~Dr.~~ Frederick Romberg. We are indebted also to Eugene McDermott, Chairman of the Executive Committee for ^{his} cooperative arrangement. / For these a recording device -- a multi-channel shallow seismic oscillograph is being constructed by MacLaughlin Electronics. With this instrument it will be possible to detect whether or not true reflections have occurred, and thus determine more reliable information about sonic wave behavior at shallow depths.

One of our immediate goals, however, is to put together an instrument or an assemblage of workable parts that will assist us in the search for the archaic Greek city of Sybaris in southern Italy,⁴ which is probably buried under 6 meters of clay. This problem and the success (with the kind assistance of M.J. ^{Aitken} ~~Anken~~ in May) in the detection of anomalies down to 5 meters (during our 1962 campaign) with the Oxford proton magnetometer are described more fully in the references cited. The MacLaughlin prototype was tested (also) last year over known walls, but no reflections were detected. This was due to the fact that the transducer did not transmit impulses into the ground with sufficient intensity to penetrate

- 4. ILN - Rainey
- Expedition - Brown
- Wellesley Alumnae Magazine - Ralph

↑
continue 1st
2 lines p. 13.

same one as described or else why not? jmett.

A portable high power transducer is being constructed (by MacLaughlin) for use in the 1963 expedition. This transducer is a transistorized electronic pulser with a peak power output of 5,000 to 10,000 watts. The pulser operates at a repetition rate of 5 pulses per second, with the frequency of the pulses controlled from 500 to 5000 cycles. The pulses are generated by applying alternating voltage, up to 15 kilovolts, to a piezoelectric element, normally resonant at a frequency much higher than the operating frequency. The circuit is highly damped to limit the "ringing" time and provide a short clean pulse. Due to the poor earth coupling and resulting inefficient energy transfer, ringing is a problem. The weight of the transducer, complete with silver cadmium battery, is about 12 lbs.

51

Sonic equipment is also being developed by Engineer Carabelli of the Polytechnical School of Milan. His experiments indicate that a sonic source of high intensity produced by an electrical spark discharge appears promising.

more than a few meters nor to be reflected. How much of the original energy was lost due to poor ground coupling is ~~now~~ known.

A forceful transducer is presently being constructed (by MacLaughlin). This consists of an electronic pulser with 5,000 to 10,000 watts peak power output. A charge is built up to 10 kilovolts⁵ and discharged (at the repetition rate of 5 cps) into ~~either~~ a piezoelectric transducer element in a non-resonant arrangement to obtain an output frequency of the order of 1000 cps. At the moment, however, the problem of coupling this stronger impulse into the ground in a practical manner remains unsolved.

5. Experiments along similar lines are being conducted also by ← Engineer Carabelli of the Polytechnical School of Milan. (Our search for Sybaris is a joint U.S. - Italian effort conducted by the University Museum of the University of Pennsylvania and the Lericci Foundation-Polytechnical School of Milan).

With these improved transducers and with the information obtained & equipment assembled by the Petty Laboratories, we hope to ~~obtain~~ detect reflections from depths of 6 meters, possibly from the buried ~~c~~ ^{Greek} city, if lucky, to "see" the buried archaic city of Sybaris.

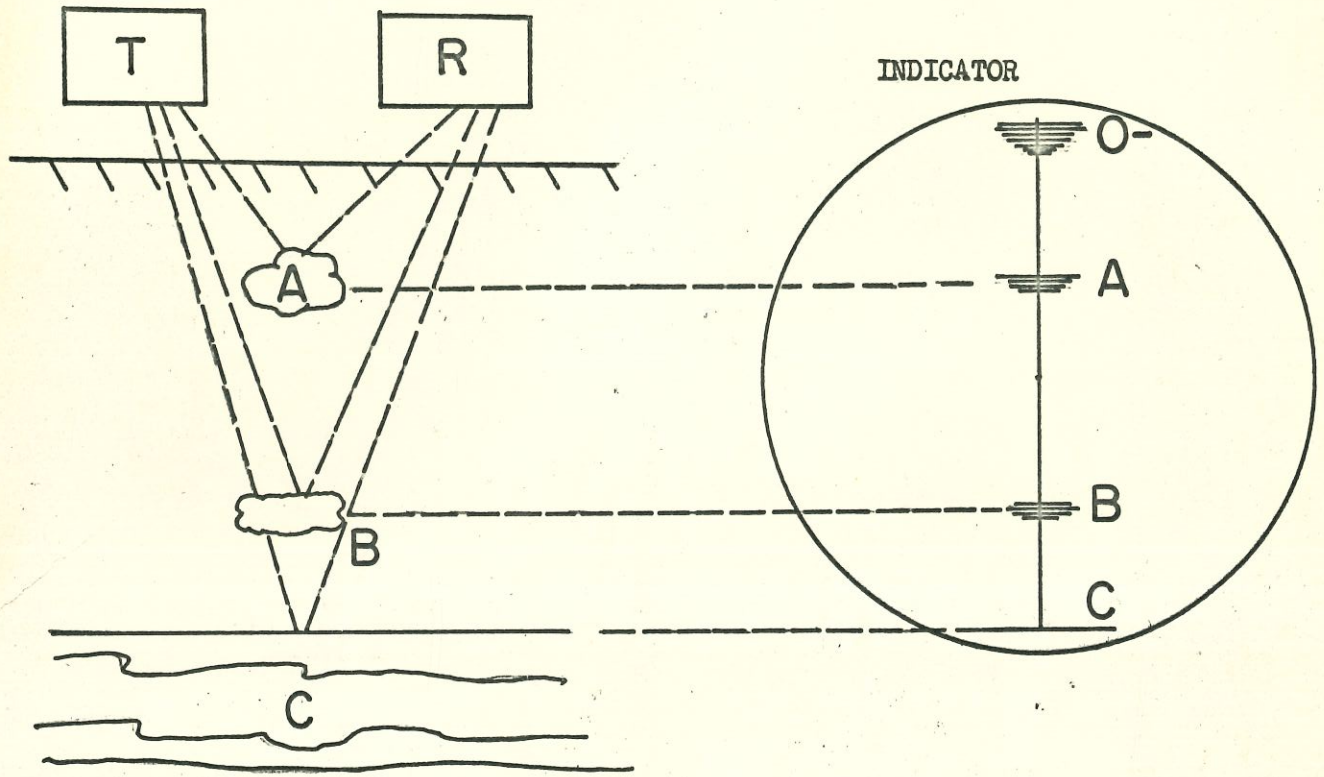
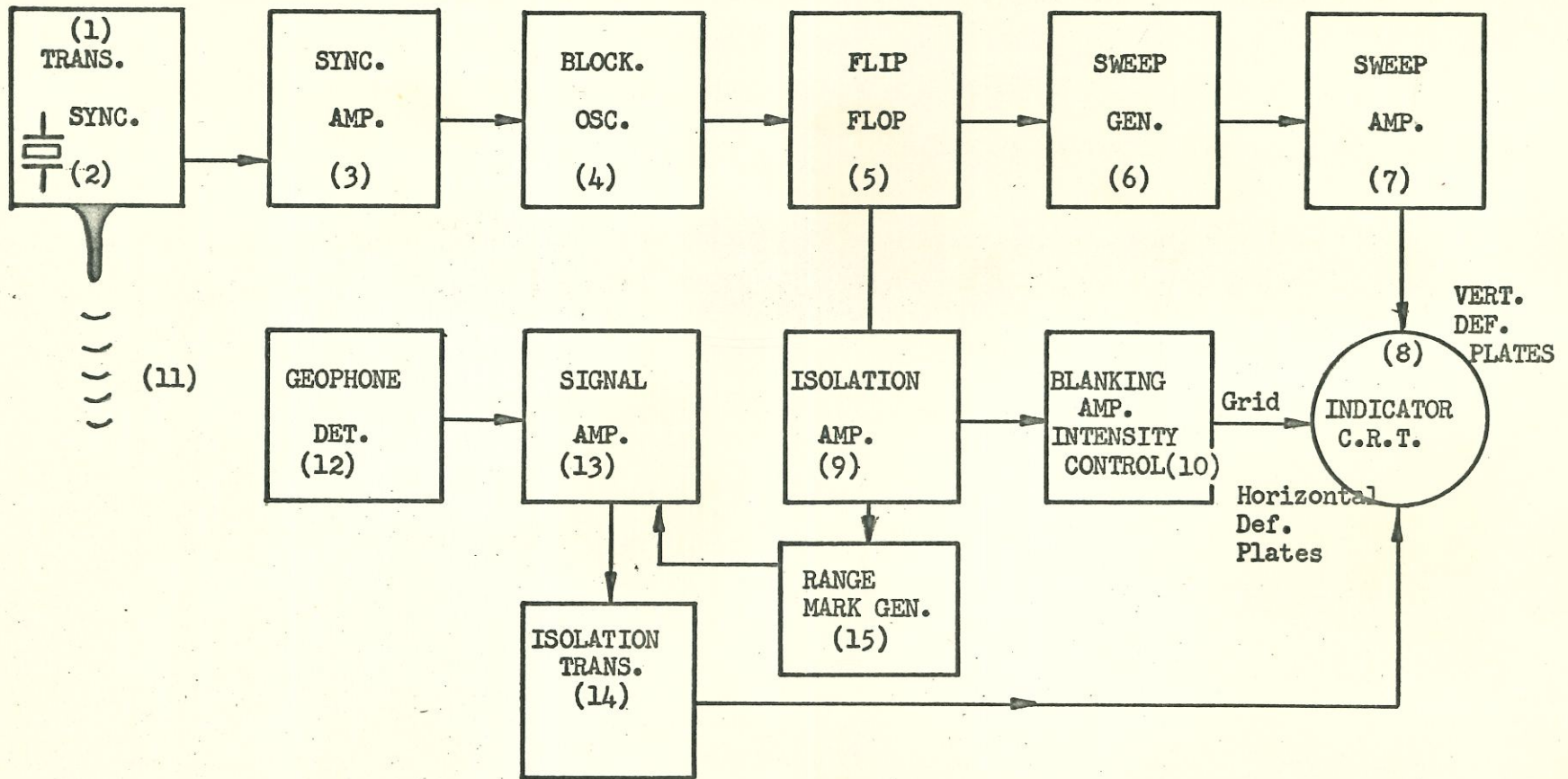


FIGURE 1.



BLOCK DIAGRAM

Figure 2.

NEW INSTRUMENTATION TECHNIQUES IN ARCHAEOLOGY

Froelich Rainey Elizabeth Ralph

During the past ten years two instruments have been adapted and developed specifically for underground exploration in archaeology. Not long after the last war Dr. Paul Fejos of the Wenner-Gren Foundation attempted to interest American archaeologists in such instruments without much success, but British, German, and Italian diggers became interested and we now have a small portable, transistorized, resistance apparatus, made in Germany, and a proton-magnetometer made in England, which are thoroughly proven and successful tools for archaeological survey. I believe that these new techniques for archaeological exploration may eventually have as much effect upon the study of prehistory as the now famous radio-carbon and potassium argon methods for dating ancient remains.

There are in all continents rich sedimentary plains at the mouths of rivers or along the sea where we may expect to find ancient settlements deeply buried beneath the silt. Conventional archaeology, to a large extent, has bypassed these rich plains where we might expect to find some of the oldest and most developed cultural deposits because there is often no evidence of the ancient remains visible upon the surface. At this stage we have two problems: to develop simpler and more efficient instruments and to convince the diggers that the techniques can be utilized by people who are not trained in geophysics.

At the University Museum we have recently established an Applied Science Center for Archaeology to carry on research and development in various new techniques applicable to archaeology. Part of our investigation during the past two years has been the testing of the resistance equipment and the proton-magnetometer for underground archaeological explorations. To do this we have joined up with the Lerici Foundation in Rome, directed by Engineer C. M. Lerici, a manufacturer of geophysical equipment and

New Instrumentation, Rainey-Ralph

steel products in Milano. For about five years he has been using resistance equipment to locate and explore Etruscan tombs in Tuscany and he has demonstrated without any doubt the efficiency of these instruments for this specific job. In the summer of 1961, our crew from ASCA at the University Museum joined the Lerici crew at Tarquinia and Cervetri north of Rome to compare the new German resistance instrument with the more elaborate and costly instrument used by the Lerici Foundation. We ran a series of parallel tests at Tarquinia and soon learned that the much simpler and less expensive German instrument designed specifically for archaeology was equally as efficient as the Italian instrument. At Tarquinia there is a vast Necropolis with many hundreds of Etruscan tombs dating from the first century before Christ, cut into the bedrock below some one, two, or three meters of surface soils, which are essentially volcanic in origin. When the Etruscans made these tombs they cut a long narrow ramp or stairway down into bedrock, then hollowed out a rectangular tomb in the bedrock with a stone door. The tombs lie anywhere from one and a half to five meters below the surface. With the resistance instrument we ran lines of readings across the Necropolis which enabled us to pick up the earth-filled ramps leading to the subterranean tombs. Apparently the earth-filled ramps give higher conductance readings than the surrounding bedrock and hence we were able to locate on graphs the position of these ramps. Once these were located it was a simple matter with a minimum amount of excavation to locate the position of the tomb. Once we had located that, by using a power-driven earth auger to drill down through the roof of the tomb we then inserted a periscope with an electric light at the base which made it possible to examine the contents of the tomb without excavation. With a system of mirrors we were also able to photograph the inside of the tomb and even to broadcast over television the view of the inside of an

R. Dicks

594-5831

Wm. Cole

Design and
Recess

Needs metal detector
or magnetometer
for locating Corner
Stone in College Hall
with metal Box in the
Raid Stone.

76 article on Brill's
History of Chemistry ACS.
p 244 - 250

New Instrumentation, R_a iney=Ralph

unexcavated tomb, simply by applying the television camera to the periscope.

Once we had demonstrated that the small inexpensive German resistance equipment was as good and even more efficient than the elaborate Italian equipment, we turned to experimentation with the British-built proton-magnetometer. ^{Under certain conditions} ~~In the~~ ~~field~~ this instrument is much more efficient than the resistance equipment because you need only one ground contact rather than four to take a reading of the magnetic intensity of the surface levels. Our system was to lay out a grid

measuring fifty by fifty meters and take a magnetic reading at one meter intervals. We then drew up a magnetic contour map of the fifty meter grid. It became evident

from these contour maps that we were accurately spotting the location of the tombs themselves rather than the earth-filled ramps. With the earth auger we could then

drill the tombs without any excavation whatever. We found it was possible to make a magnetic grid fifty meters square in about one day and on the average we could

locate and explore five or six tombs in one day. This was obviously much more efficient than the resistance method. ~~We suspect~~ ^{We suspect that it was} None of us are quite sure just what geophysical

~~condition made~~ ¹ it possible to detect the location of the tombs on our magnetic grids but they ~~were~~ ^{ly} so accurate that we rarely missed a tomb in any of our drilling

operations. ^{because this was a region of volcanic origin with high magnetic intensity. This is the reverse of the usual application of this instrument for the location of iron objects, pottery deposits, or soil disturbances, that is, features which}

Similar tests were made at Cervetri where bedrock and surface soils differ considerably. However our results at Cervetri were equally successful and it seems that from now on the proton-magnetometer will replace the resistance

equipment in the exploration for these Etruscan tombs at several sites in Tuscany. ^{exhibit higher magnetic intensity than the surrounding earth.}

New Instrumentation, Rainey-Ralph

From the Etruscan area north of Rome we switched our operations to the plain of Sybaris in Calabria in the south of Italy. There we know from Greek and Roman records that the Greek city of Sybaris was destroyed by the Crotoni in the sixth century before Christ. The ruins are supposed to lie somewhere near the Crati river on a broad plain where the overflow of the river in the spring of has created very deep sedimentary deposits largely volcanic soils. Our problem there was to locate the actual site of the city which should be composed of ruined stone buildings, pavements, walls, etc., probably now lying several meters below the surface. During the preceding spring the Lerici Foundation engineers utilizing the resistance equipment had located a segment of buried stone wall on this plain. In October utilizing the proton-magnetometer we were able to trace that buried wall for eight hundred meters. At some points the top of the wall lay only a meter under the surface but at other points it was buried as deep as three meters. Test excavation showed that the anomaly recorded by the proton-magnetometer very precisely located the wall but in these test excavations we never succeeded in locating the base of the wall because there were no pumps available to carry away the water in our deepest excavations. We did manage to reach a depth of four and a half meters at one point on the wall but we have no idea how much deeper it may go. The construction of the wall and the pottery found with it indicate that it is of Roman construction at the upper levels, but there are some indications that the lower part of the wall was built some centuries before Christ and we believe that the base of it may have been built in the sixth century before Christ. Its function remains a mystery. We have not yet found either end, nor the base, but we know that ~~there~~ ^{it} is a major work on the plain of Sybaris and must have some connection with a series of several cities built there during several centuries. It may be a retaining wall for the Crati river, or a harbor wall.

gradiometer, a differential-type

It is now our plan to return to Sybaris in April with an improved proton-magnetometer, and with adequate pumps and excavating equipment so that we can probe the lowest levels on the plain. We also expect to follow the wall as far as possible with these electronic instruments, but together with the instruments, we are using two or three different types of drills to probe the anomalies discovered with the instruments.

In the meantime at the ASCA we have developed a sonic instrument utilizing ^a high frequency impulse ^{at ultrasonic frequencies} to locate underground features, ^{This} which ~~will~~ will also be tested at Sybaris this spring. Our investigations so far indicate that each of the two proven instruments has certain limitations depending upon the type of site. For example, the resistance apparatus depends upon certain conditions of soil and humidity, and in some cases where we have very dry soils it will not operate at all. Moreover at distances of three or four meters an object less than a meter in diameter cannot be spotted because its bulk relative to the volume of the soil being measured for conductance is not sufficient to record as an anomaly. The proton-magnetometer was limited in depth penetration. We could rarely pick up any feature from below three meters in depth. Also this instrument naturally depends upon contrasts between magnetic and non-magnetic materials. In Italy the condition for the proton-magnetometer seemed to us ideal because we had non-magnetic stone features buried in magnetic soils. In other sites these conditions naturally do not prevail and the instrument is therefore not useful. We have hopes that the high-frequency sonic device, ^{ground moisture} unaffected by humidity and magnetic conditions, ^{also} will be useful in most sites. We ~~also~~ expect to get greater penetration.

With our investigations so far, we conclude that these electronic instruments have been proved ^{as} a more efficient way to carry out archaeological surveys in those areas where there are no archaeological features obvious on the surface, but that improvements and simplifications are necessary if they are to be

adopted widely by field archaeologists. We think that the high-frequency sonic device may fill some of these requirements and at least it is one step in the right direction. The great advantage of this is speed in carrying out a survey in any given area but more than that with the improvement of such instruments we should be able to discover very important ancient remains on these sedimentary plains which would be impossible to locate with normal conventional archaeological methods.

SUGGESTED RESEARCH

McAur
Please use
wave
capacitor
Techniques

Tests made with a high frequency seismic unit have indicated that much work remains to be done on transducers and coupling methods. Also, there seems to be considerable discrepancy between theoretical attenuation and actual attenuation. The coupling problem is common to both pulsed and C.W. systems. Any work done in this region would be of great value. The coupling problem with the short ranges used in Archeology is not critical but a good coupling system would increase the resolution of the system and would reduce the power required from the transducers.

The frequencies at present of interest are from 1000 cycles to about 20,000 cycles. Transducer design data in this region is scanty. Attenuation measurements would be valuable. There seems to be a variation in velocity with a variation in intensity of the transmitted signal. This velocity variation is not predicted by classical theory. The attenuation also seems to be several times greater than predicted and increases rapidly with frequency.

How much of the attenuation is due to poor coupling, is difficult to determine. Experiments are in progress on transducer design and coupling methods with the intent of decreasing the size and increasing the efficiency as portability and light weight is of great importance with the many measurements necessary to examine an area.

SUGGESTIONS FOR A SMALLER
CESIUM MAGNETOMETER

The Varian Associates Model 4920 Precision Portable Cesium Magnetometer is the best magnetometer that has been designed for archaeological prospecting. It is the most sensitive and the most rapid to use for making grids (the Model V-4971 Portable Search Magnetometer with audio readout is faster for line traverses, but much slower for grids due to the necessity of adjusting the dial for each precise reading).

The Model 4920, even though readily portable, is too heavy. The main reason for this is the current drain, especially when used in the difference mode of operation. Each sensor and the readout draw approximately 0.6 amps, i.e., a total of 1.8 amps. This high current drain necessitates the use of large batteries which weigh 18 lbs. and even ones of this size last for only 4 hours. *Now 7 batteries - check type*

Another consideration is cost. With each sensor costing \$5000, the market for these instruments is necessarily limited.

We feel that if the instrument could be redesigned and the cost reduced, there would be the possibility of greatly increased sales to archaeologists. The aspects of the new design which we suggest are as follows:

- 1) Sensors: Now Model 49-544
 - a) Smaller, if possible, and with less current drain.
 - b) Strain - relieved rugged cable connectors. (None of the present cable connectors ^{is} are meant for field use and they break frequently.)

2) Readout: Now Model 49-116

a) Somewhat smaller and simplified. For example, the External Synchronization feature is not needed, and possibly other components could be reduced in size or eliminated. (Specific details of these revisions could best be worked out between the engineers at Varian and Beth Ralph.)

b) Strain - relieved rugged cable connectors.

3) Batteries: Now five 6 volt Eveready NP8-6/T Rechargeable.

a) Lowering of the voltage requirements (now 24 to 30v) of both sensors and readouts possibly to 18v or less, would reduce the number of batteries required. For further weight reduction, reduced current drain is also desired.

b) Strain - relieved rugged cable connectors.

4) Cables

Also, with strain-relieved rugged connectors.

Since the cables and, especially, the connectors have been the causes of frequent breakdowns in the field, these would have to be improved before the instruments could be used regularly by archaeologists without the assistance of physical scientists.

April 2, 1970

E.K. Ralph